

Induced Circular Dichroism Spectra of β - and γ -Cyclodextrin Complexes with Indazolinone and Related Compounds

MASAHIRO KAWAMURA and MIWAKO HIGASHI*

Materials Science, The Graduate School of Science and Engineering, Ibaraki University, 4-12-1 Nakanarusawa, Hitachi 316-8511, Japan

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Abstract

The magnetic circular dichroism (MCD) spectra of indazolinone, isatine, and 3-iminoisoindolinone and the induced circular dichroism (ICD) spectra of the inclusion complexes with β - or γ -cyclodextrins (CDs) have been measured. The spectra are interpreted by results of the ZINDO calculations. In the presence of cyclodextrin, the OH indazolinone tautomer is main structure that is consistent with that in the DMSO solution. The structures of the inclusion complexes are very different because of the scale of the cavity of cyclodextrin or position of quinone in molecules.

Introduction

The structure of dihydro-3*H*-indazol-3-one (indazolinone) in the solid state is different from that in the DMSO solution. Ballesteros *et al.* [1] concluded that the tautomer in the solid state is **1a** which is in the helical packing of the dimer. In the DMSO solution, it is shown that the OH tautomer (**1b**) is main structure by the assignment of NMR spectra. In this work, we have considered the structures of the inclusion complexes of indazolinone, 1*H*-indole-2,3-dione (isatine, **2**), and 3-imino-1*H*-isoindol-1-one (3-iminoisoindolinone, **3**), which are iso- π -electron systems of indazolinone (Figure 1).

The guest molecule of an appropriate size can be accommodated into cavity of cyclodextrin (CD) to form inclusion complex. The shape and sign of induced circular dichroism (ICD) spectra of the CD inclusion complex provide precise structural information. Harata and Uedaira [2] have measured the ICD spectra of the β -CD inclusion complexes with naphthalene derivatives and estimated the orientation of the guest molecule within the cavity of the β -CD. Some authors have investigated the signs of the ICD spectra of the β -CD and γ -CD inclusion complexes [3–6]. The signs of ICD bands are correlated with directions of the transition moments of the guest molecule in the cavity of the CD. If the direction of the electric dipole moment in the guest molecule is parallel to the long axis of CD cavity, then the rotational strength gives a positive ICD value and the transition with the electric dipole moment perpendicular

to the long axis of CD gives a negative ICD value. Therefore, ICD spectra are a very useful tool to estimate an orientation of the guest molecule within the cavity of CD if the direction of the electric dipole moment in the guest molecule is known. The magnetic circular dichroism (MCD) spectra of some quinones have been measured and assigned by semi-empirical calculations [7–9]. The MCD spectra are very effective tool for assignment of the electronic transitions.

For the CD inclusion complexes, the strong split-type ICD spectra like an exciton coupling effect have been observed [10–12]. The result of exciton splitting of

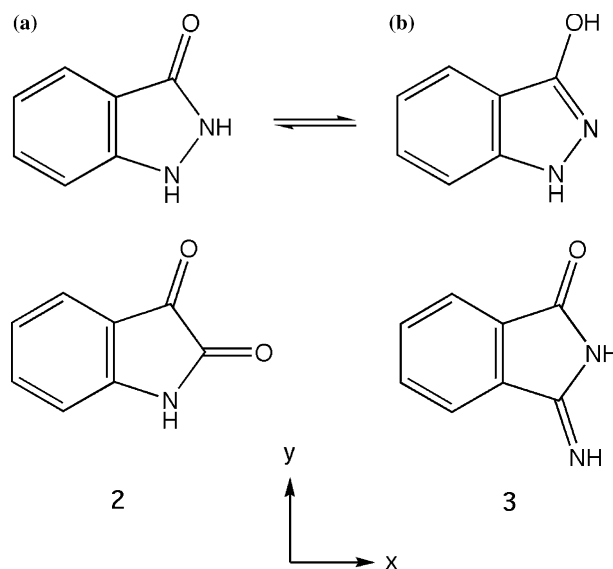


Figure 1. The structure of indazolinone tautomer, isatine, and 3-iminoisoindolinone.

*Author for correspondence: E-mail: higashi@mx.ibaraki.ac.jp

excited states in the molecular aggregates may appear a split ICD spectral pattern if spatial interactions such as stacking between two guest molecules is present. The split-type ICD spectra show that the dimer of guest molecules is trapped within the CD cavities.

Experimental

Indazolinone (Sigma–Aldrich Co.), isatin (Wako Pure Chemical Industries), and 3-iminoisoindolinone (Sigma–Aldrich Co.) were recrystallized twice from ethanol. β - and γ -CD (Kanto Chemical Co.) was purified by repeated recrystallizations from dist. H₂O. Spectral-grade solvents (ethanol) were used as received. The absorption spectra were recorded on a Jasco U-Best35 spectrophotometer. The ICD spectra were measured using a Jasco J-600C spectropolarimeter. The stoppered silica cells of 1 and 5 cm path-lengths were used. The concentrations of β - and γ -CDs were maintained in all experiment at 9.00×10^{-3} M. The MCD spectra were recorded on a Jasco J-600C spectropolarimeter with a 1.32 T electromagnet. All measurements were carried out at room temperature.

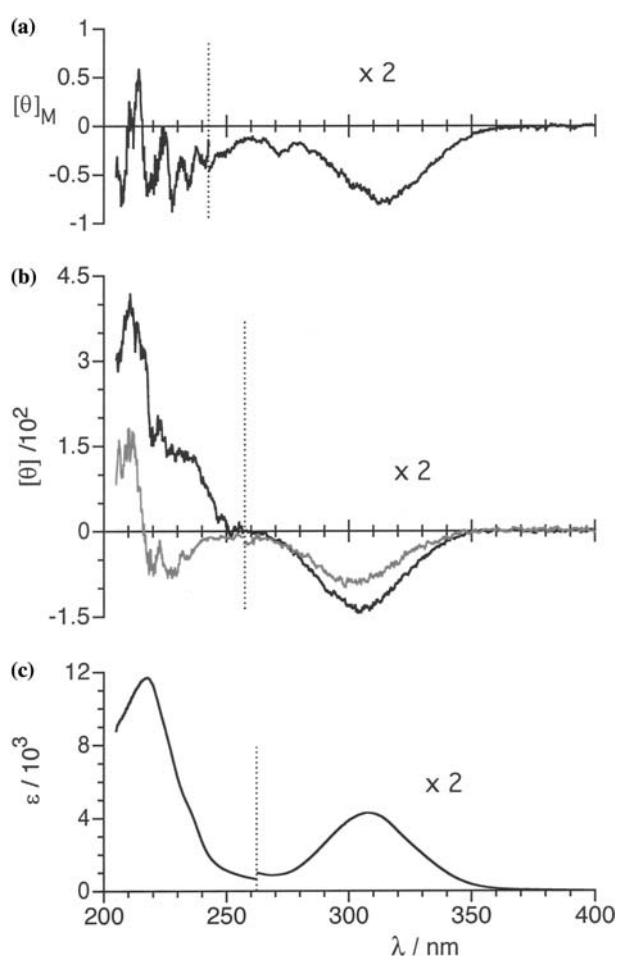


Figure 2. The MCD spectrum (a) and absorption spectrum (c) of indazolinone in ethanol, and ICD spectrum (b) of β -CD (black) and γ -CD (grey) complexes with indazolinone in 10% ethanol-aqueous solution.

Calculation

The molecular structure of indazolinone (**1a**) [1] and isatine [13] were determined from X-ray diffraction data. It is obtained that a molecule of isatine is virtually planar and C(=O) – C(=O) bond considerably larger than the normal value. Frolova *et al.* [13] concluded that the lengthening is apparently caused by the presence of oxygen atoms which have electron acceptor properties in relation to the indole nucleus.

In the absence of relevant experimental structural data of **1b** and 3-iminoisoindolinone, the geometry was optimized by using the PM3 method in MOPAC [14]. With the geometry obtained by the PM3 method and experimental geometries, we calculated the electronic transition energies and transition moments by using ZINDO method [15].

Results and discussion

The absorption and MCD spectra of indazolinone together with the ICD spectra of the inclusion complexes with β - and γ -CDs are shown in Figure 2. The MCD and ICD spectra below 210 nm cannot be observed due to the absorption of solvents. The ZINDO calculation of indazolinone (**1a**, **1b**) are shown in Table 1. The MCD spectrum of indazolinone shows

Table 1. Calculated results of transition energies (λ_{\max}/nm), oscillator strengths (f) by the ZINDO method

| Band | λ_{\max} | f | Assignment |
|-----------------------------|------------------|-------|------------|
| Indazolinone (1a) | | | |
| S ₁ | 329 | 0.001 | $n\pi^*$ |
| S ₂ | 302 | 0.170 | $\pi\pi^*$ |
| S ₃ | 248 | 0.130 | $\pi\pi^*$ |
| S ₄ | 230 | 0.283 | $\pi\pi^*$ |
| S ₅ | 214 | 0.706 | $\pi\pi^*$ |
| Indazolinone (1b) | | | |
| S ₁ | 303 | 0.094 | $\pi\pi^*$ |
| S ₂ | 260 | 0.089 | $\pi\pi^*$ |
| S ₃ | 233 | 0.012 | $n\pi^*$ |
| S ₄ | 228 | 0.787 | $\pi\pi^*$ |
| S ₅ | 224 | 0.360 | $\pi\pi^*$ |
| Isatine | | | |
| S ₁ | 506 | 0.000 | $n\pi^*$ |
| S ₂ | 345 | 0.001 | $n\pi^*$ |
| S ₃ | 335 | 0.083 | $\pi\pi^*$ |
| S ₄ | 276 | 0.012 | $\pi\pi^*$ |
| S ₅ | 231 | 0.829 | $\pi\pi^*$ |
| S ₆ | 216 | 0.252 | $\pi\pi^*$ |
| 3-Iminoisoindolinone | | | |
| S ₁ | 349 | 0.002 | $n\pi^*$ |
| S ₂ | 288 | 0.012 | $n\pi^*$ |
| S ₃ | 282 | 0.031 | $\pi\pi^*$ |
| S ₄ | 258 | 0.060 | $\pi\pi^*$ |
| S ₅ | 233 | 0.519 | $\pi\pi^*$ |
| S ₆ | 216 | 0.920 | $\pi\pi^*$ |

negative MCD bands around 315 and 270 nm. From the ZINDO calculation, there are at least two $\pi\pi^*$ absorption bands (S_2 and S_3 in **1a**, S_1 and S_2 in **1b**) in the longer wavelength region (260–360 nm). The directions of transition moments of indazolinone are shown in Figure 3. The sign of the first band (around 310 nm) in the ICD spectrum is negative. From the sign of ICD band and direction of transition moment (S_2 in **1a**, S_1 in **1b**), it is supposed that the short molecular axis (about y axis) of indazolinone is perpendicular to the molecular axis of β - or γ -CD. The directions of the transition moments in indazolinone tautomer (**1b**) are divided into the two groups. One group is the transition moment directions of S_1 and S_2 which are around the short molecular axis (red arrows). The other group is the transition moment directions of S_4 and S_5 which are around the long molecular axis (blue arrows). In the ICD spectra of the β -CD inclusion complex of indazolinone, the sign of the first band (260–360 nm) is negative and the sign of the second band (210–260 nm) is positive. The signs of ICD bands are consistent with signs of ICD values estimated from the directions of transition moments. In indazolinone tautomer (**1a**), directions of transition moments in S_2 , S_3 , S_4 , and S_5 $\pi\pi^*$ transitions suggest the negative, positive, negative,

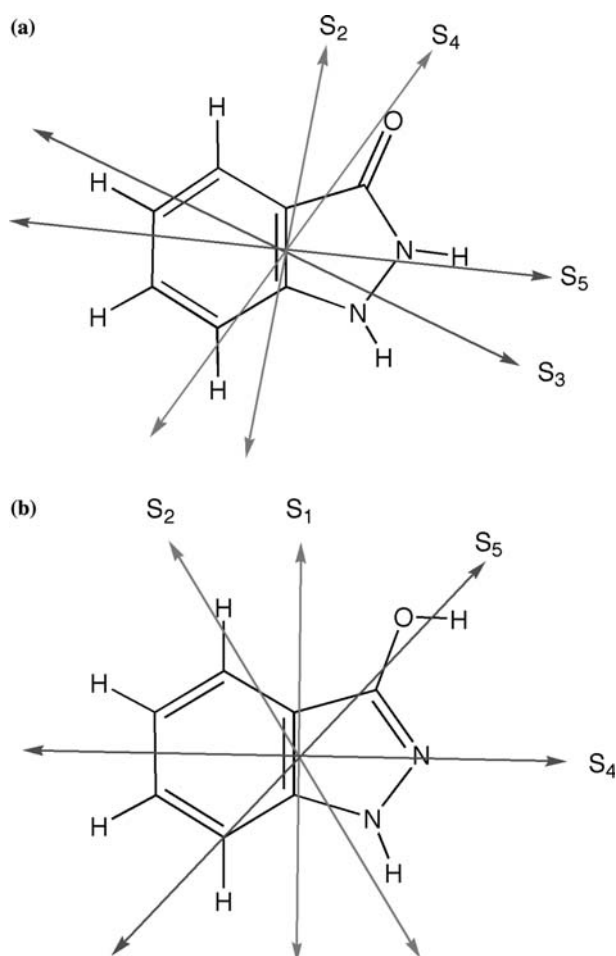


Figure 3. The directions of the transition moments in indazolinone tautomers (**1a**, **1b**).

and positive ICD values. Therefore, it is concluded that the tautomer (**1b**) is dominant structure in CD inclusion complex. That conclusion is consistent with the structure of indazolinone in DMSO solution [1]. For the γ -CD complex of indazolinone, the ICD spectrum (210–225 nm) shows the sign alternation. The \pm signal alternation in ICD spectra, split-type ICD spectra, shows that the dimer of indazolinone is formed only in the presence of γ -CD, since the cavity of the γ -CD is larger than the cavity of β -CD.

The absorption and MCD spectra of isatine together with the ICD spectra of the inclusion complexes are shown in Figure 4. The MCD spectrum and ZINDO calculation show that the band in the wavelength region (350–500 nm) is S_3 , the band in the wavelength region (240–260 nm) is S_4 , and the band in the wavelength region (240–260 nm) is S_5 . In the Figure 5, the direction of the transition moments of S_5 is perpendicular to the transition moments direction of S_3 and S_4 . We conclude that the cyclodextrin is capped by isatine since the signs of the ICD spectra of isatine inclusion complex with β - or γ -CD show all negative bands.

The absorption and MCD spectra of 3-iminoisindolinone together with the ICD spectra of the inclusion complexes are shown in Figure 6. The MCD spectra and

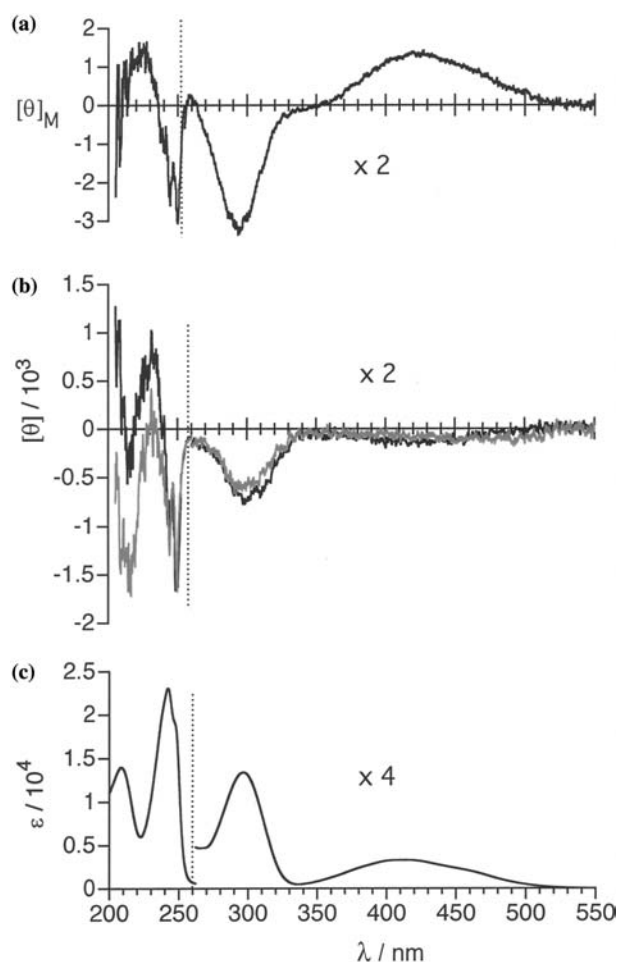


Figure 4. The MCD spectrum (a) and absorption spectrum (c) of isatine in ethanol, and ICD spectrum (b) of β -CD (black) and γ -CD (grey) complexes with isatine in 10% ethanol-aqueous solution.

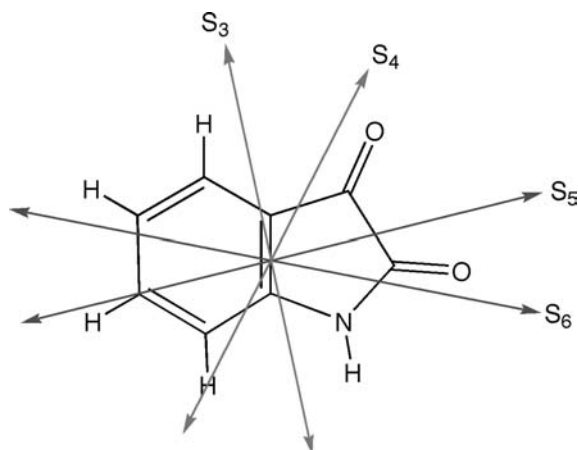


Figure 5. The directions of the transition moments of isotatine.

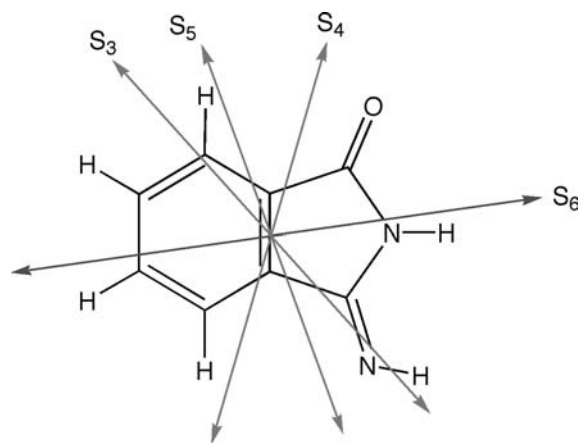


Figure 7. The directions of the transition moments of 3-iminoisoindolinone.

ZINDO calculation show that there are two $\pi\pi^*$ absorption bands (S_3 and S_4) in the wavelength region (265–370 nm). The directions of the transition moments of S_3 and S_4 are around the short molecular axis (Figure 7). The signs of ICD spectra in the wavelength

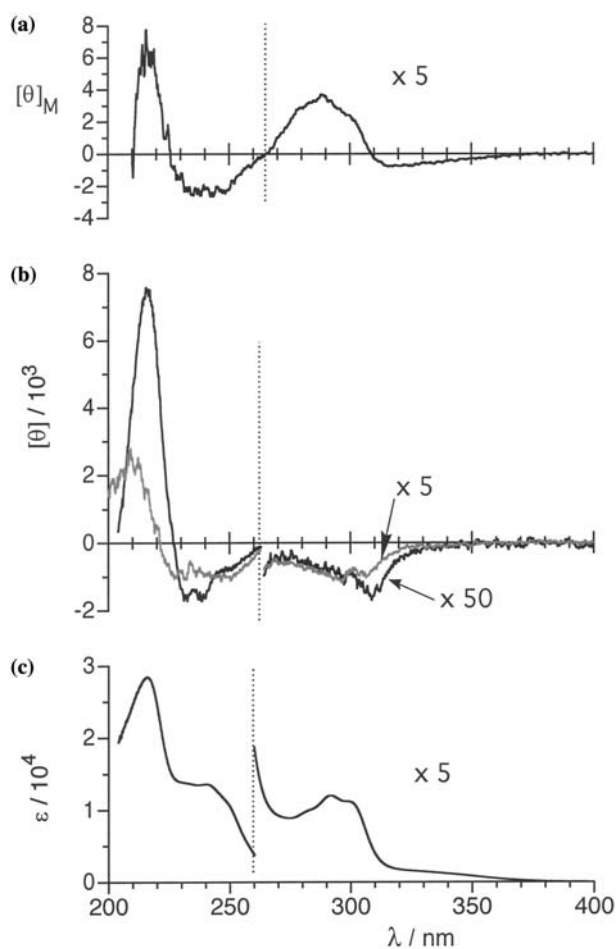


Figure 6. The MCD spectrum (a) and absorption spectrum (c) of 3-iminoisoindolinone in ethanol, and ICD spectrum (b) of β -CD (black) and γ -CD (grey) complexes with 3-iminoisoindolinone in 10% ethanol-aqueous solution.

(265–370 nm) are negative. Therefore, it is concluded that the long molecular axis of 3-iminoisoindolinone is parallel to the molecular axis of the β - or γ -CD for the inclusion complexes. In the wavelength region (215–265 nm), there is the \pm sign alternation in the ICD spectra of the 3-iminoisoindolinone inclusion complexes. In the wavelength region (210–225 nm), there are positive ICD band in β -CD complex and the positive MCD band. On the other hand, the positive and negative bands are in the wavelength region (210–225 nm) of the γ -CD inclusion complexes. The sign alternation in an absorption band shows that the dimer complexes are in the γ -CD, since cavity of γ -CD is larger than the β -CD.

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